Optical properties and photoablation of photosensitive thin films by 13.5 and 6.7 nm light

Chen-Y. Yeh,[1] Jia-J. Sung,[1] Grace H. Ho*,[1] Hsuan-T. Chang,[1] Yi-Y Kuo,[1] Yu-C. Tzeng,[1] Chih-W. Yeh,[1] Hok-S. Fung[2] and Bor-Y. Shew[2]
[1]Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan
[2]National Synchrotron Radiation Research Center, Hsinchu 300, Taiwan
*graceho@nuk.edu.tw

A vacuum-compatible specular reflectometer was used to measure the refractive index (n), extinction coefficient (k) and thin film thickness (T) values of polymethylmethacrylate (PMMA), polystyrene/t-butylacrylate copolymer films with or without photoacid generator (denoted as GJH and GJ) at 13.5 nm and 6.7 nm, and it was also used for conducting *in situ* exposure and actinic investigation on the photoablation rates of the samples against EUV and BEUV irradiation. The thickness loss of the film by photoablation was cross-examined by a profilometer as a function of the EUV and BEUV exposure dose. The photoablation rates as functions of irradiation wavelengths, film thicknesses, and material compositions are presented here.

Introduction

Extreme ultraviolet (EUV) lithography using 13.5 nm light is the most likely choice for IC manufacturing beyond the 16 nm technology node, whereas 6.X nm light is suggested to be used beyond EUV (BEUV).

In our previous study [1], we have demonstrated the SEUVR (specular EUV reflectivity) method as a unique technique to simultaneously measure the optical properties of EUV photoresist materials and at the same time to monitor the photoablation effect of photosensitive thin films. This work uses SEUVR and SBEUVR methods to quantify photoablation and a α-step profilometer and specular ellipsometry to verify our results.

Experiment

- **Light source**: synchrotron radiation at 13.5 nm and 6.7 nm from the BL08A beamline of NSRRC.
- **Vacuum-compatible specular reflectometer**

SEUVR (wavelength at 13.5nm)

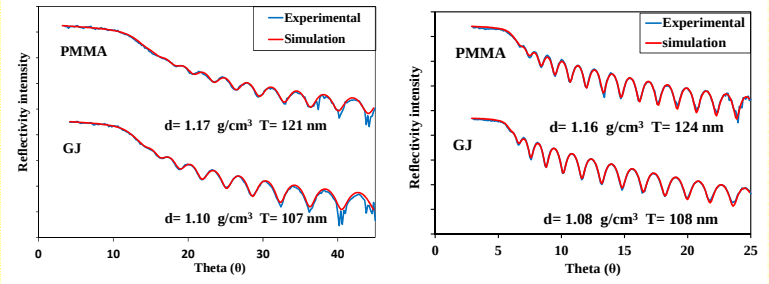
Step	Entrance slit (μm)	End slit (μm)	θ(°)	2θ(°)	Accumulated Dose (mJ/cm²)
(1) Actinic Inspection	15	10	0-45	0-90	30
(2) *in situ* exposure	200	200	11-18		100 (up to 25 times)

SBEUVR (wavelength at 6.7nm)

Step	Entrance slit (μm)	End slit (μm)	θ(°)	2θ(°)	Accumulated Dose (mJ/cm²)
(1) Actinic Inspection	150	30	0-25	0-50	6.0
(2) *in situ* exposure	1000	1000	5.5-9		4.0 (up to 64 times)

- **Reflectivity simulation tool** - PANalytical (X'Pert reflectivity version 1.3).

Examples of the simulation:

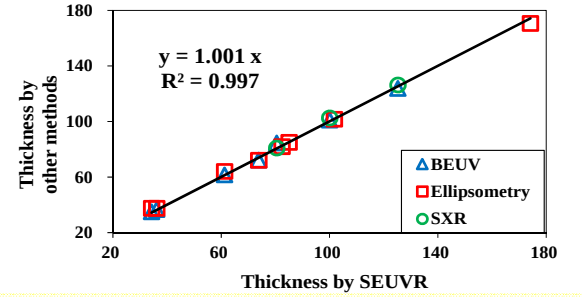


- **Samples:**

1. PMMA
2. GJ (polystyrene(61wt%) + t-butylacrylate(39wt%)) from DuPont™
3. GJH (GJ (94wt%)+ $(C_6H_5)_3SC_4F_9SO_3$ (5wt%)+ Tetrabutylammonium hydroxide (1wt%))

Result

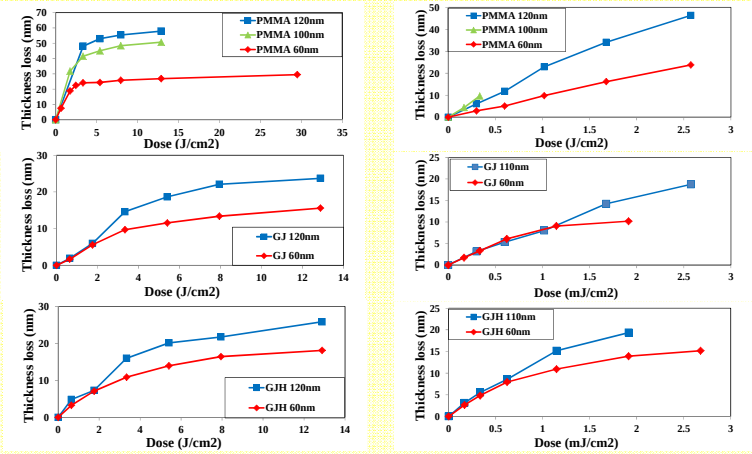
- **Film thicknesses measured by SE, SXR, SBEUVR vs. by SEUVR**



- The feasibility of using SEUVR and SBEUVR for the film thickness measurement is thus confirmed.

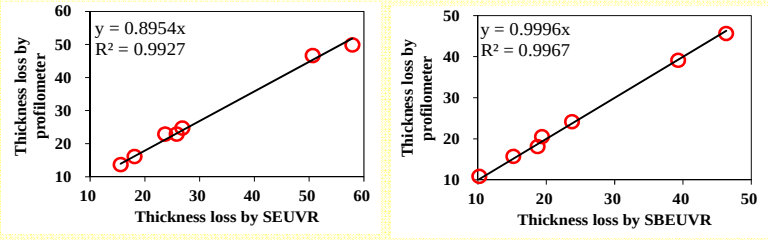
- **Photoablation (thickness loss) as a function of the EUV and BEUV exposure dose :**

SEUVR (wavelength at 13.5nm) SBEUVR (wavelength at 6.7nm)



- Negligible thickness loss with added exposures at the high dosage region, and the thickness loss in the high-dose plateau region shows dependency on material compositions (PMMA vs. GJ or GJH) and initial film thicknesses (60 vs. 120 nm), both upon EUV and BEUV irradiation.
- Thickness independent (GJ and GJH) or thickness dependent (PMMA) ablation rates were observed in the low dosage region.
- The photoablation rate of PMMA upon EUV irradiation is 0.01 nm mJ^{-1} cm^2, which is consistent with the literature value of 0.008 nm mJ^{-1} cm^2 [2].

- **Measured by α-step profilometer and compare with SEUVR and SBEUVR**



- The SEUVR and SBEUVR are feasibility to study the EUV and BEUV photoablation effect *in situ* and actinically.

summary

- We have conducted two benchmarking tests to demonstrate the specular EUV and BEUV spectrometer at NSRRC in Taiwan, which is capable to measure optical properties and the photoablation effect of photosensitive thin films.
- We have successfully measured optical properties and the photoablation effect of PMMA and DuPont's resists at 13.5 nm and 6.7 nm.
- The thickness loss of PMMA, GJ, and GJH with high EUV and BEUV dosages is thickness dependent, whereas the photoablation rate of PMMA upon 13.5 nm irradiation is 0.011 nm mJ^{-1} cm^2, a value which is consistent with the literature value.

Reference

[1] Ho, G.H.; Kang, F.-H.; Shih, Y.-H.; Fung, H.-S.; Ku, W.-P.; Cheng, Y.-S. and Wu, P.-J. *Proc. SPIE*. **2010**, 7636, 16362U, P1-12.
[2] Barkusky, F.; Peth, C.; Bayer, A. and Mann, K., *J. Appl. Phys.*,**2007**, 101, 124908, P1-6.

Acknowledgement

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2. DuPont™ is thanked for providing free GJ samples.